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**Cai et al.**

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(54) **FABRICATING SHALLOW-TRENCH ISOLATION SEMICONDUCTOR DEVICES TO REDUCE OR ELIMINATE OXYGEN DIFFUSION**

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**H01L 29/06** (2006.01)  
**H01L 29/78** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **H01L 21/76224** (2013.01); **H01L 29/0649** (2013.01); **H01L 29/7846** (2013.01)

(58) **Field of Classification Search**  
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USPC ..... 438/436, 437  
See application file for complete search history.

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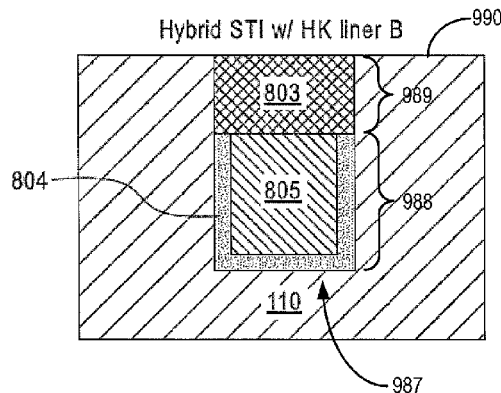
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(57) **ABSTRACT**

A method is disclosed for forming a semiconductor device. A first opening is formed for an STI on a semiconductor substrate and a first process is performed to deposit first oxide into the first opening. A second opening is formed to remove a portion of the first oxide from the first opening and second process(es) is/are performed to deposit second oxide into the second opening and over a remaining portion of the first oxide. A portion of the semiconductor device is formed over a portion of a surface of the second oxide. A semiconductor device includes an STI including a first oxide formed in a lower portion of a trench of the STI and a second oxide formed in an upper portion of the trench and above the first oxide. The semiconductor device includes a portion of the semiconductor device formed over a portion of the second oxide.

**15 Claims, 9 Drawing Sheets**



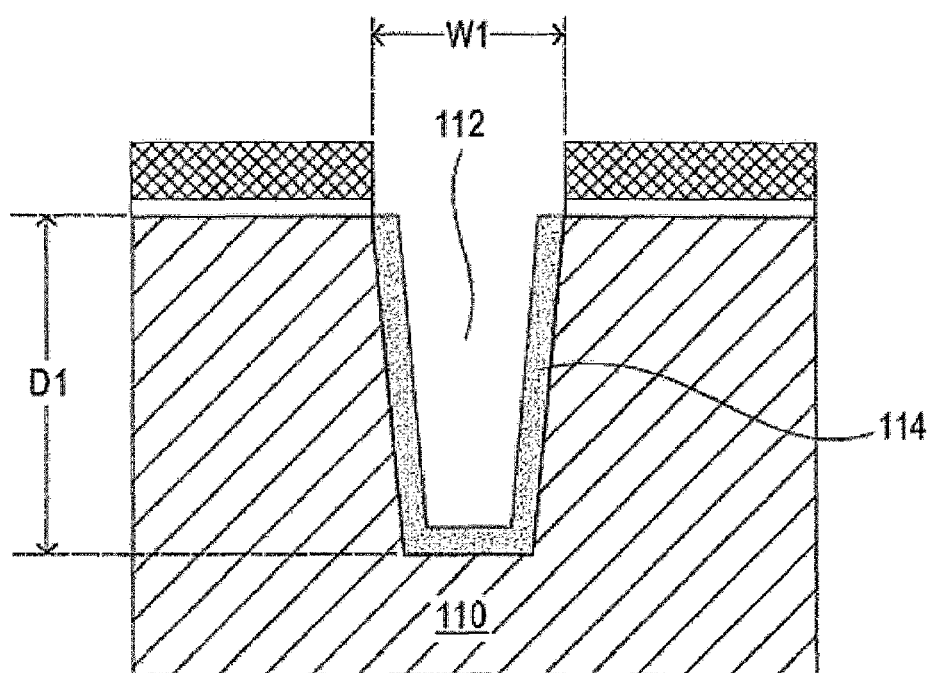


FIG. 1

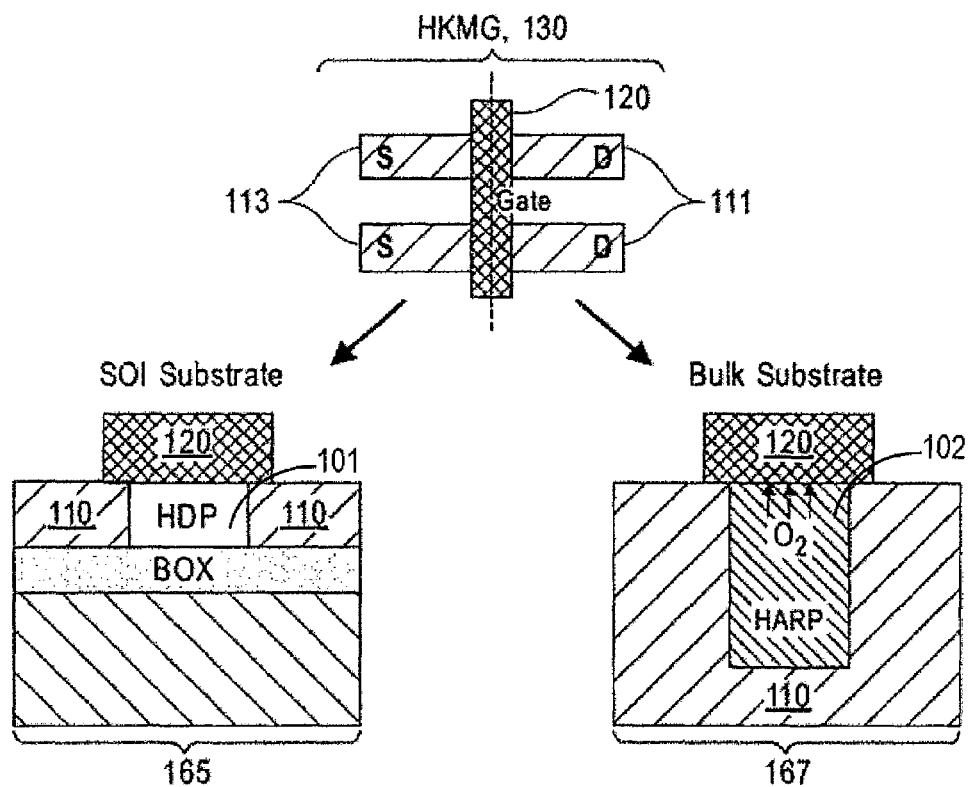


FIG. 2

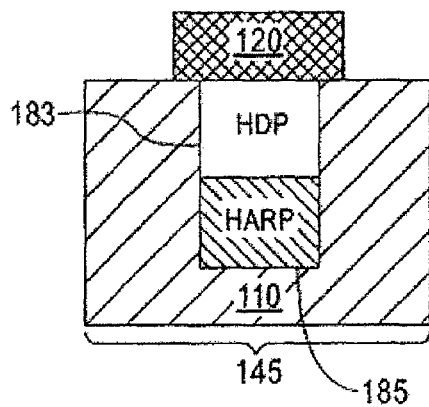


FIG. 3A

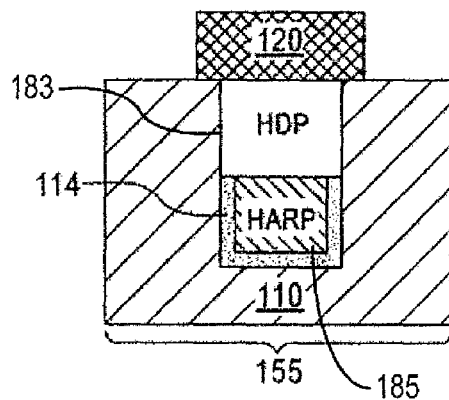


FIG. 3B

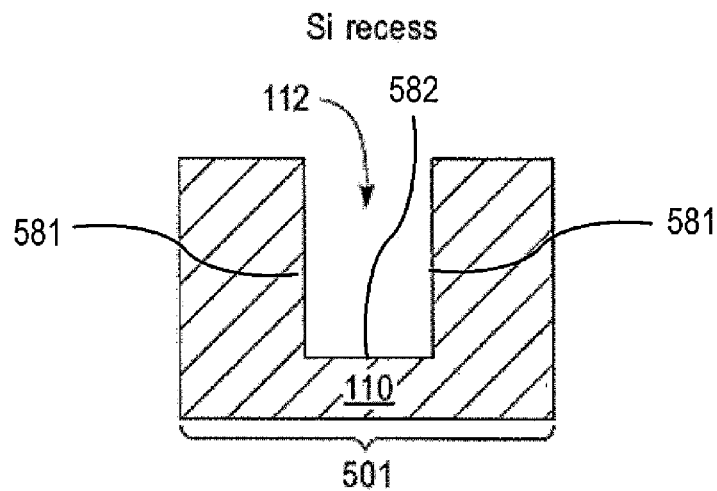


FIG. 4A

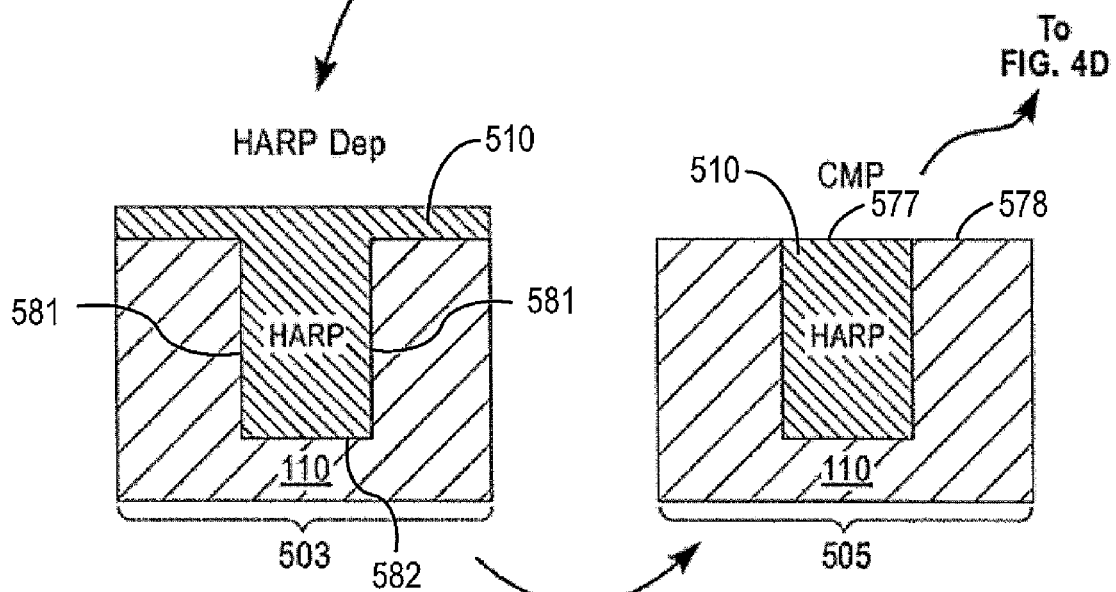
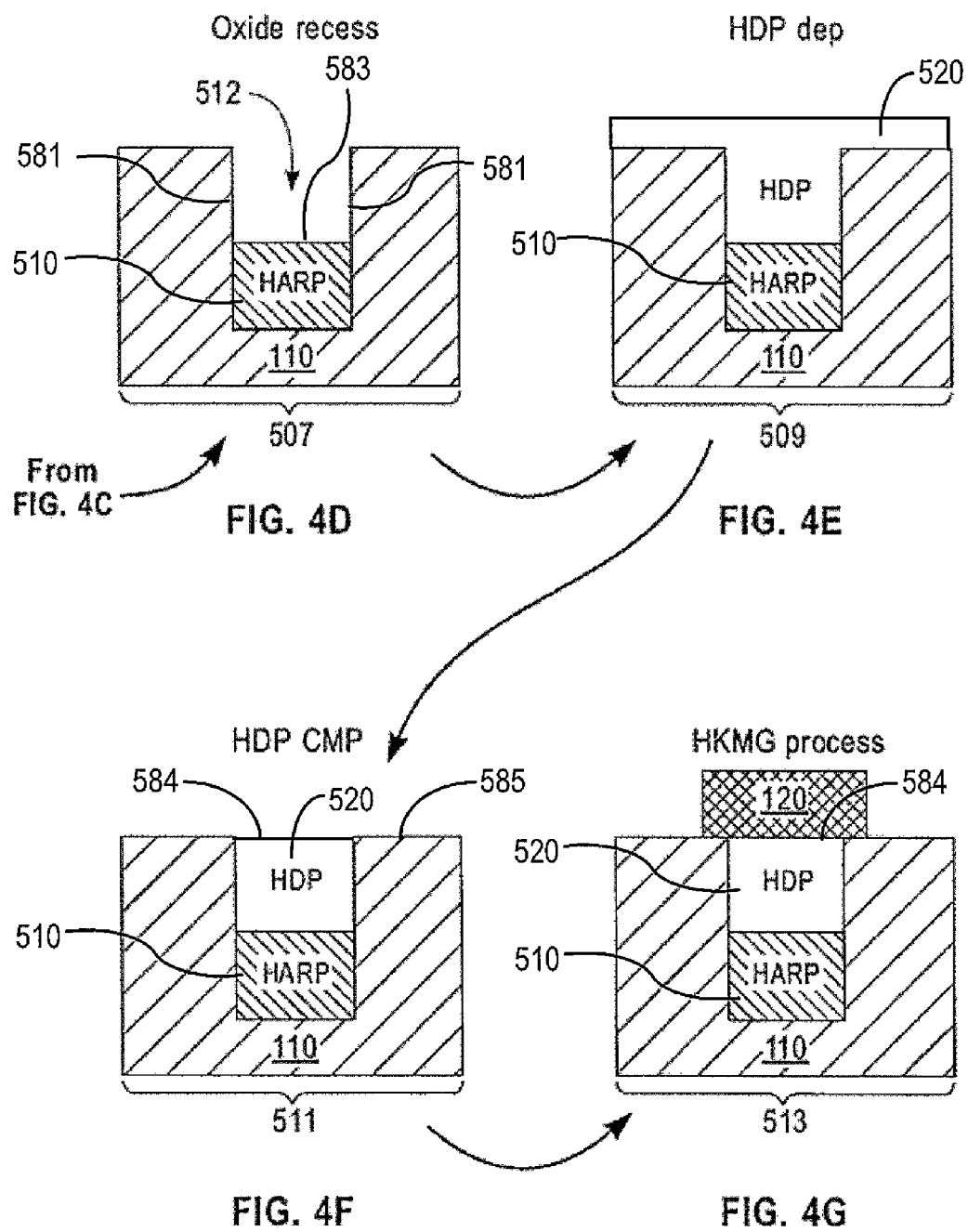


FIG. 4B

FIG. 4C



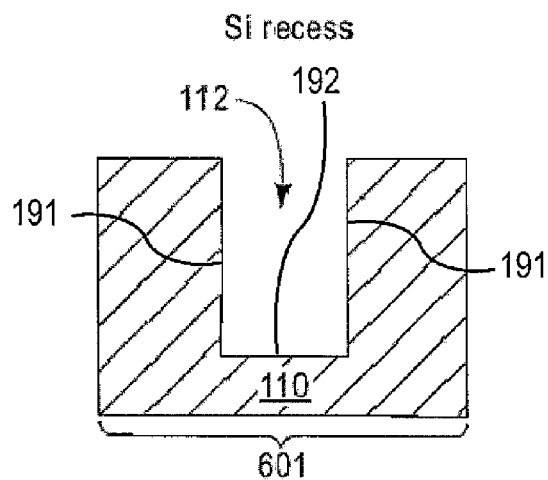


FIG. 5A

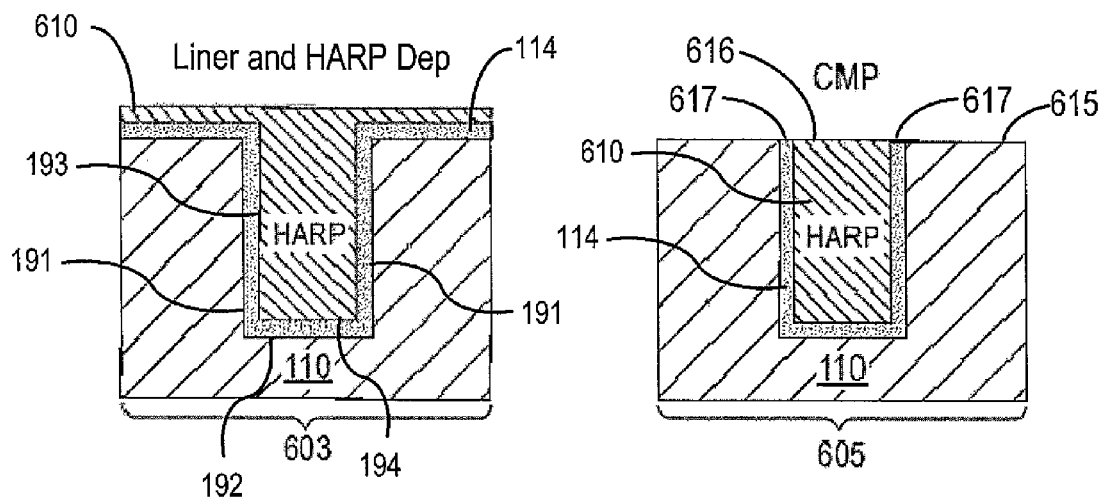


FIG. 5B

FIG. 5C

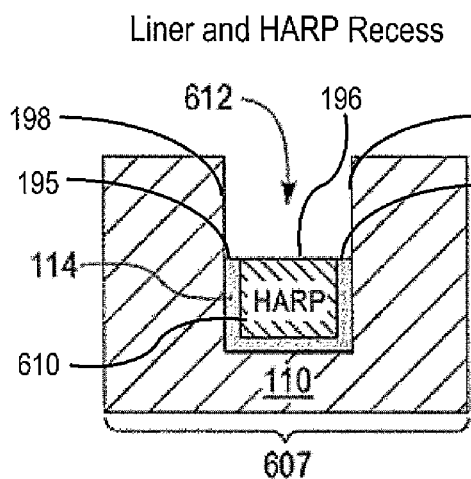


FIG. 5D

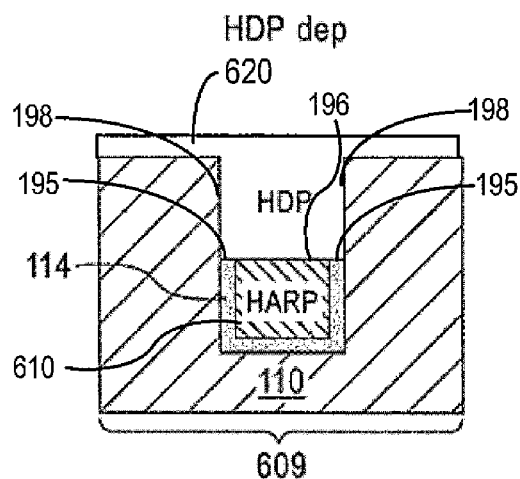


FIG. 5E

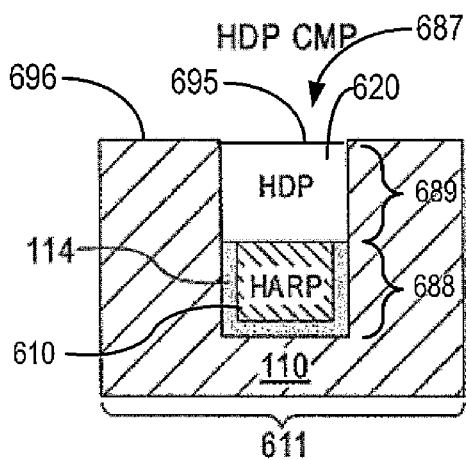


FIG. 5F

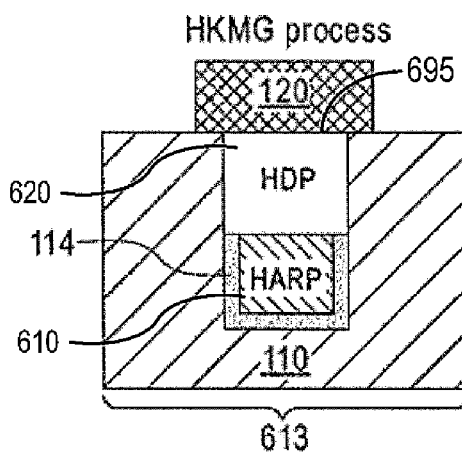


FIG. 5G

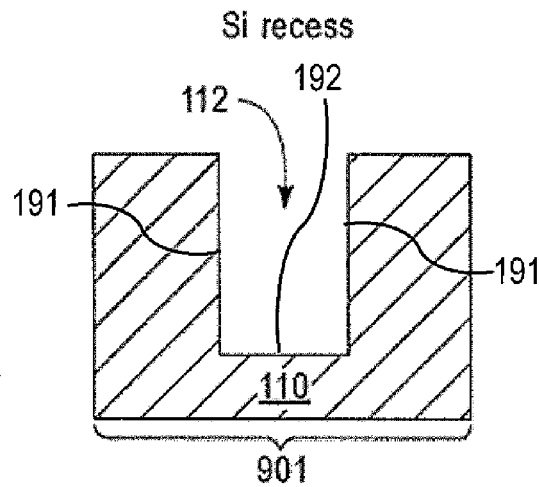


FIG. 6A

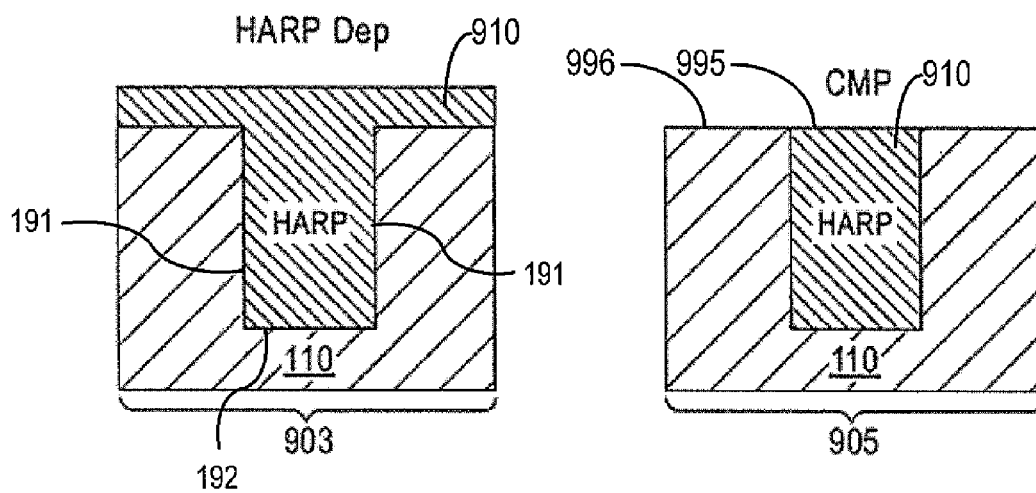


FIG. 6B

FIG. 6C



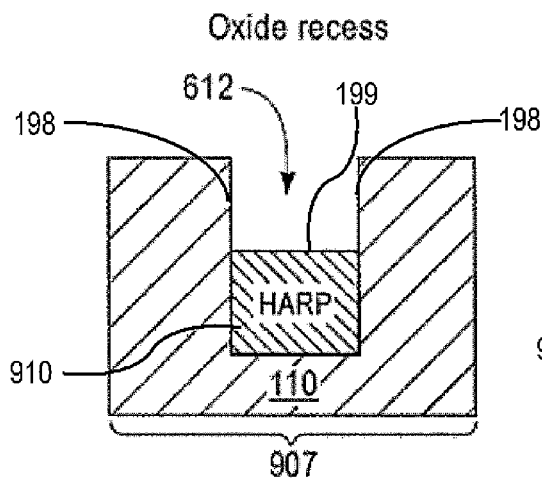


FIG. 6D

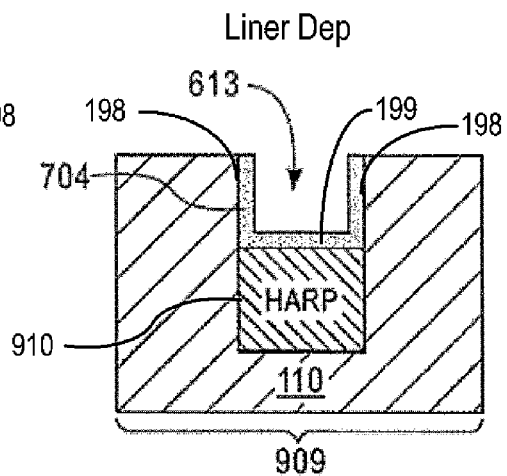


FIG. 6E

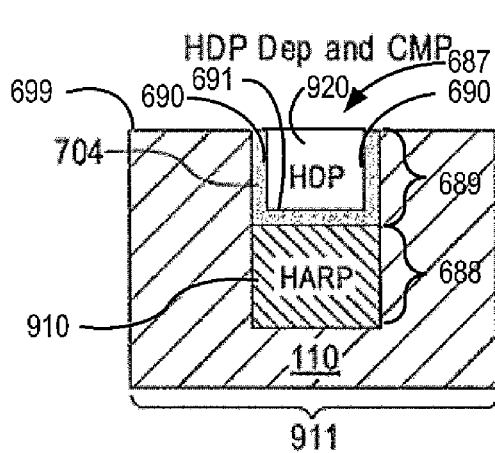


FIG. 6F

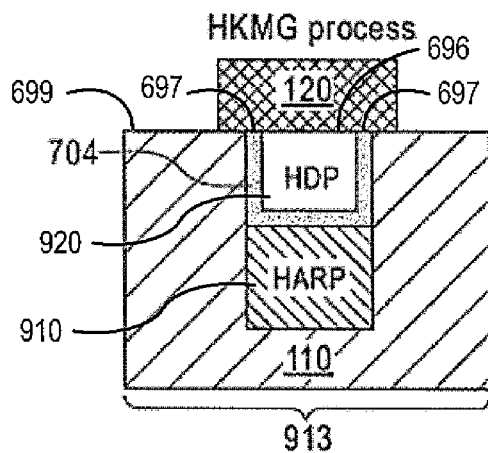


FIG. 6G

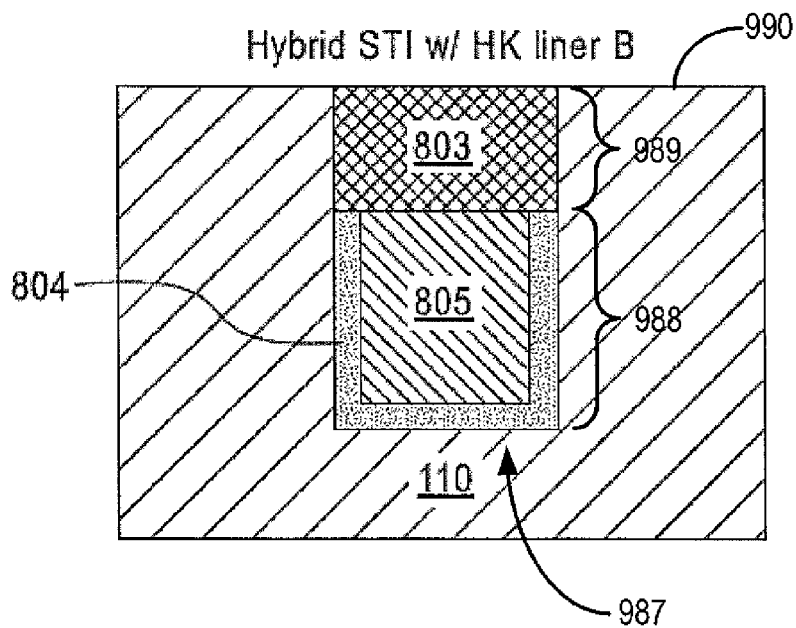


FIG. 7

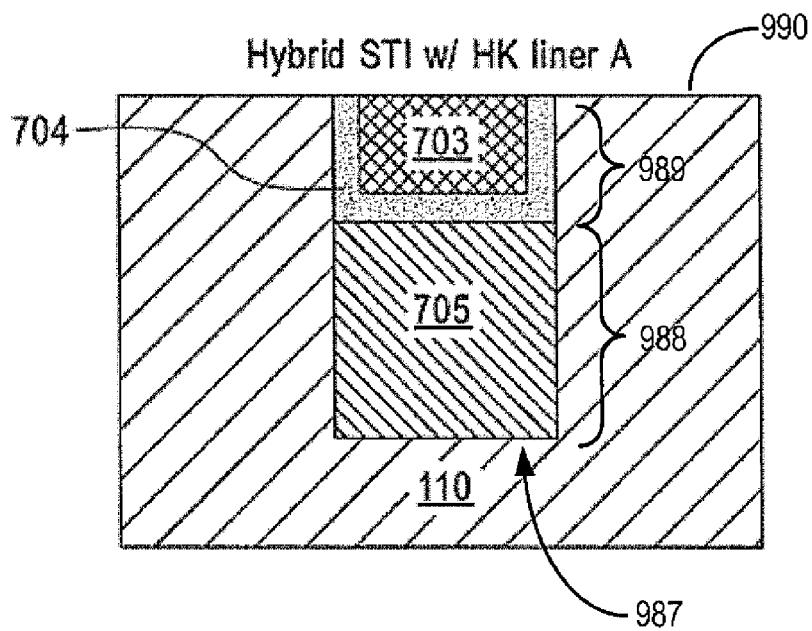


FIG. 8

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# FABRICATING SHALLOW-TRENCH ISOLATION SEMICONDUCTOR DEVICES TO REDUCE OR ELIMINATE OXYGEN DIFFUSION

## TECHNICAL FIELD

The exemplary embodiments of this invention relate generally to semiconductor devices and more particularly to structures and manufacturing methods for reducing or eliminating oxygen diffusion in shallow-trench isolation (STI) semiconductor devices.

## BACKGROUND

Integrated circuits are formed on the surfaces of semiconductor substrates such as silicon. Semiconductor devices are isolated from one another through the use of isolation structures formed at the surfaces of the respective semiconductor substrates. The isolation structures include field oxides and shallow trench isolation (STI) regions.

A common design objective is to decrease or minimize the required physical size of an integrated circuit. This down-scaling may be facilitated by using STI regions as isolation structures. FIG. 1 illustrates an exemplary STI region. An opening 112 is formed in a substrate 110, for example, by etching. The opening 112 has an aspect ratio, which is equal to the ratio of depth D1 to width W1. This aspect ratio increases as integrated circuits are scaled down in size. For 40 nm technology and below, the aspect ratio may be greater than 7.0. A liner 114 is formed in the opening 112. Next, an oxide, preferably a silicon oxide, is filled into the opening 112, until the top surface of the oxide is higher than the top surface of the substrate 110.

The oxide is filled into the opening 112 using either high-density plasma chemical vapor deposition (HDPCVD, also known as HDP), or a high aspect-ratio process (HARP). HARP is used to fill trenches having relatively high aspect ratios, whereas HDP is used in situations where oxygen content is to be minimized. For example, the HDP technique is used to fill gaps with aspect ratios no greater than 6.0, whereas the HARP technique is used to fill gaps with aspect ratios that are greater than 6.0.

Another distinction between HARP and HDP relates to the concentration of oxygen in the oxide that is filled into the opening 112. In general, HARP provides a higher concentration of oxygen in oxide formed by HARP as compared to oxide formed by HDP. This higher oxygen concentration is a concern when fabricating high dielectric constant metal gate (HKMG) transistors because the oxygen may change the threshold voltage of the transistor to an unacceptable extent.

If the oxygen migrates or diffuses into a gate stack of the STI semiconductor device where the device comprises an HKMG transistor, the threshold voltage of the HKMG transistor may change significantly. Moreover, if the STI semiconductor device includes a divot, oxygen diffusion into the gate stack will be further enhanced.

## SUMMARY

This section provides examples of possible implementations of exemplary embodiments. This section is not intended to be limiting.

A first exemplary embodiment is a method for forming a semiconductor device including a shallow trench isolation. The method includes forming a first opening for the shallow trench isolation on a semiconductor substrate and performing

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a first process to deposit first oxide into the first opening. The method also includes forming a second opening to remove a portion of the first oxide from the first opening and performing at least one second process to deposit second oxide into the second opening and over a remaining portion of the first oxide. The method further includes forming at least a portion of the semiconductor device over and contacting at least a portion of a surface of the second oxide.

Another exemplary embodiment is a semiconductor device. The semiconductor device includes a shallow trench isolation formed in a semiconductor substrate. The shallow trench isolation includes a first oxide formed in a lower portion of a trench of the shallow trench isolation and a second oxide formed in an upper portion of the trench and above a surface of the first oxide. The semiconductor device includes a portion of the semiconductor device formed over and contacting at least a portion of a surface of the second oxide.

A further exemplary embodiment is an article of manufacture for forming a semiconductor device comprising a shallow trench isolation. The article of manufacture includes a computer-readable storage medium that contains computer program instructions. Execution of the computer program instructions by at least one data processor results in performance of operations that include at least the following: forming a first opening for the shallow trench isolation on a semiconductor substrate; performing a first process to deposit first oxide into the first opening; forming a second opening to remove a portion of the first oxide from the first opening; performing at least one second process to deposit second oxide into the second opening and over a remaining portion of the first oxide; and forming at least a portion of the semiconductor device over and contacting at least a portion of a surface of the second oxide.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIG. 1 is a simplified cross-sectional view of an exemplary shallow trench isolation in a semiconductor device.

FIG. 2 is a simplified cross-sectional view showing formation of a shallow trench isolation, high dielectric constant metal gate (HKMG) transistor using either a high aspect ratio process or a high-density plasma process.

FIG. 3A is a simplified cross-sectional view setting forth a first exemplary shallow trench isolation and FIG. 3B is a second exemplary shallow trench isolation in a semiconductor device for reducing or eliminating oxygen diffusion.

FIG. 4, including FIGS. 4A through 4G, sets forth a first exemplary method for fabricating a shallow trench isolation in a semiconductor device using a high aspect ratio process followed by a high-density plasma process.

FIG. 5, including FIGS. 5A through 5G, sets forth a second exemplary method for fabricating a shallow trench isolation in a semiconductor device using a high aspect ratio process followed by a high-density plasma process wherein a liner may serve, e.g., as an oxygen barrier or an oxygen sink or both.

FIG. 6, including FIGS. 6A through 6G, sets forth a third exemplary method for fabricating a shallow trench isolation in a semiconductor device using a high aspect ratio process followed by a high-density plasma process wherein a liner may serve, e.g., as an oxygen barrier or an oxygen sink or both.

FIG. 7 sets forth a first illustrative shallow trench isolation in a semiconductor device fabricated using the method of FIG. 5.

FIG. 8 sets forth a second illustrative shallow trench isolation in a semiconductor device fabricated using the method of FIG. 6.

#### DETAILED DESCRIPTION

FIG. 2 is a simplified cross-sectional view showing formation of a shallow trench isolation, high-dielectric-constant metal gate (HKMG) transistor **130** using either a high aspect ratio process (HARP) on a bulk silicon substrate **167**, or a high-density plasma (HDP) process on a Silicon On Insulator (SOI) substrate **165**. Notably, for both the HARP process and the HDP process, oxygen diffusion, migration, and releases from the HKMG transistor **130** during front-end-of-line (FEOL) thermal processes may adversely impact the threshold voltage of the HKMG transistor **130**. The threshold voltage ( $V_t$ ) is a voltage level that determines whether a transistor will be on or off. For example, in cases where the HKMG transistor **130** is an nFET, if the gate **120** is above  $V_t$ , then the nFET transistor is on. If the gate **120** is below  $V_t$ , then the nFET transistor is off. In cases where the HKMG transistor **130** is a pFET, complementary behavior will be observed. In other words, if the gate **120** of the pFET transistor is above  $V_t$ , then the pFET transistor is off. If the gate **120** is below  $V_t$ , then the pFET transistor is on.

The HKMG transistor **130** includes one or more source **113** elements, one or more drain **111** elements, and a gate **120**. For SOI wafers such as the SOI substrate **165**, HDP can be used to form the isolation region **101** in the HKMG transistor **130** due to the presence of a buried oxide (BOX) layer **125** underneath the substrate **110**. However, in the case of bulk wafers such as the bulk substrate **167**, HARP is used to provide the relatively deep trenches for isolation region **102** required for isolation. In general, HDP provides semiconductor devices (e.g., especially the oxide formed using HDP) having lower oxygen concentration relative to (e.g., oxides formed using) HARP. For applications involving high-k metal gates (HKMGs), the presence of oxygen can degrade gate performance. For example, undesirable oxygen diffusion and penetration may occur into the gate **120** stack, thus providing a semiconductor device with an unpredictable  $V_t$  that may differ substantially from the desired or target  $V_t$ .

As elements in semiconductor devices have been reduced to sizes on the order of 45 nanometers or smaller, non-metal gate dielectrics such as silicon dioxide begin to lose their insulating properties and exhibit too much current leakage. In order to address the current leakage problem, a hafnium-based dielectric layer may be employed with a gate electrode comprised of one or more metals. The resulting combination yields a high dielectric constant (or high k). In this context, k refers to the ability of a material to hold an electric charge. Illustratively, the gate **120** is a HKMG having a threshold voltage denoted as  $V_t$ .

FIG. 3A is a simplified cross-sectional view setting forth a first exemplary shallow trench isolation (STI) and FIG. 3B is a simplified cross-sectional view setting forth a second exemplary STI in a semiconductor device for reducing or eliminating oxygen diffusion and migration. The first and second exemplary STIs are both fabricated using HARP deposition followed by HDP and chemical mechanical planarization (CMP). By performing both the HARP process and the HDP process, a first exemplary hybrid STI **145** or a second exemplary hybrid STI **155** is provided that can be fabricated on a bulk substrate **110** (FIGS. 1 and 2) which provides isolation of a semiconductor device and also addresses undesired oxygen diffusion and ingress into the gate **120** region (FIGS. 2 and 3). The first exemplary hybrid STI **145** in FIG. 3A is fabricated

by performing HDP on an upper portion of a HARP region to form an HDP region **183** and a remaining HARP region **185**. A gate **120** is then added which may, but need not, be a HKMG. The second exemplary hybrid STI **155** in FIG. 3B is fabricated using an optional liner **114**. The optional liner **114** at least partially surrounds or partially encases or adjoins the outer perimeter of the remaining HARP region **185**. The optional liner **114** may be fabricated using any of a high-k material, an oxygen sink, and/or an oxygen barrier. An oxygen sink is any insulator that can absorb oxygen efficiently, such as  $\text{HfO}_2$  and/or  $\text{HfSiO}_4$ . An oxygen barrier is any insulator that can block oxygen diffusion such as  $\text{SiN}$ . Thus, one purpose of the optional liner **114** is to serve as an oxygen sink or oxygen barrier for absorbing oxygen that may otherwise diffuse into the gate **120** region.

FIG. 4, including FIGS. 4A through 4G, sets forth a first exemplary method for fabricating a shallow trench isolation in a semiconductor device using a HARP process followed by a HDP process. At block **501** as shown in FIG. 4A, a recess or opening (e.g., a trench for STI) **112** is formed in a silicon substrate **110**. The formation exposes side surfaces **581** and a bottom surface **582**. Next, at block **503** as shown in FIG. 4B, a process of HARP deposition is performed to deposit oxide **510** in the opening **112**. The oxide **510** at least partially conforms to and contacts the surfaces **581**, **582**. The oxide that was deposited using HARP is polished using, e.g., chemical mechanical planarization (CMP) at block **505** as shown in FIG. 4C. The polishing aligns a top surface **577** of the oxide **510** with a top surface **578** of the substrate **110**.

A recess **512** is formed in the deposited oxide at block **507** as shown in FIG. 4D. The recess in this example exposes a top surface **582** of the oxide **510**. Next, at block **509** as illustrated by FIG. 4E, a process of HDP deposition is used to fill the recess **512** with oxide **520**. The oxide **520** at least partially conforms to and contacts the surfaces **581** of the substrate **110** and the top surface **583** of the oxide **510**. The oxide **520** that was deposited using HDP is polished using CMP at block **511** as illustrated by FIG. 4F. A top surface **584** of the oxide **520** thus aligns with a top surface **585** of the substrate **110**. At block **513** as shown in FIG. 4G, a high-k metal gate **120** is formed (e.g., via deposition and patterning) above (e.g., and in contact with) a surface **584** of the polished oxide that was deposited using HDP. The resulting semiconductor device reduces or minimizes undesired oxygen diffusion and ingress from the deposited oxide into the gate **120** region.

FIG. 5, including FIGS. 5A through 5G, sets forth a second exemplary method for fabricating a shallow trench isolation in a semiconductor device using a high aspect ratio process followed by a high-density plasma process. The method of FIG. 5 uses an optional liner **114** (see, e.g., FIG. 5B) that is fabricated using any of a high-k material, an oxygen sink, or an oxygen barrier. The liner forms to and contacts the inside surface of the opening **112**. An oxygen sink is any insulator that can absorb oxygen efficiently, such as  $\text{HfO}_2$  and/or  $\text{HfSiO}_4$ . An oxygen barrier is any insulator that can block oxygen diffusion such as  $\text{SiN}$ . Thus, one purpose of the optional liner **114** is to serve as an oxygen sink or oxygen barrier for absorbing oxygen that may otherwise diffuse into the gate **120** region. At block **601** as illustrated by FIG. 5A, a recess or opening **112** is formed in a silicon substrate **110**. The opening **112** has exposed side surfaces **191** and a bottom surface **192**. Next, at block **603** as shown in FIG. 5B, a process of liner and HARP deposition is performed to deposit a liner **114** (which at least partially conforms to and contacts the surfaces **191**, **192**) and oxide **610** in the opening **112** wherein the liner **114** at least partially encases the deposited oxide **610**. The oxide **610** at least partially conforms to and contacts

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the side surfaces 193 and bottom surface 194 of the liner 114. The liner 114 and the oxide 610 that was deposited using HARP is polished using chemical mechanical planarization (CMP) at block 605 as shown in FIG. 5C, which aligns a top surface 616 of the oxide 610 and top surfaces 617 of the liner 114 with a top surface 615 of the substrate 110.

A recess or opening 612 is formed in the substrate 110 and is formed to remove deposited oxide 610 and liner 114 at block 607 as illustrated by FIG. 5D. Formation of the recess 612 exposes top surface 196 of the oxide 610, top surfaces 195 of the liner 114, and surfaces 198 of the substrate 110. Next, at block 609 as shown in FIG. 5E, a process of HDP deposition is used to fill the recess 612 with oxide 620. The oxide 620 at least partially conforms to and contacts the surfaces 195, 196, and 198. The oxide 620 that was deposited using HDP is polished using CMP at block 611 as illustrated by FIG. 5F. The polishing aligns a top surface 695 of the oxide 620 with a top surface 696 of the substrate 110. It can be seen that the oxide 620 fills an upper portion 689 (e.g., relative to the surface 696 of the substrate 110) of the trench 687 and the oxide 610 and liner 114 fill a lower portion 688 (e.g., relative to the surface 696 of the substrate 110) of the trench 687. At block 613 as shown in FIG. 5G, a high-k metal gate 120 is formed above the polished oxide 620 that was deposited using HDP and over and in contact with the surface 695 of the oxide 620. The resulting semiconductor device reduces or minimizes undesired oxygen diffusion and ingress from the deposited oxide into the gate 120 region.

FIG. 6, including FIGS. 6A through 6G, sets forth a third exemplary method for fabricating a shallow trench isolation in a semiconductor device using a high aspect ratio process followed by a high-density plasma process. The method of FIG. 6 uses an optional liner 704 (see, e.g., FIG. 6E) that is fabricated using any of a high-k material, an oxygen sink, or an oxygen barrier. An oxygen sink is any insulator that can absorb oxygen efficiently, such as  $\text{HfO}_2$  and/or  $\text{HfSiO}_4$ . An oxygen barrier is any insulator that can block oxygen diffusion such as SiN. Thus, one purpose of the optional liner 704 is to serve as an oxygen sink or oxygen barrier for absorbing oxygen that may otherwise diffuse into the gate 120 region. At block 901 as shown in FIG. 6A, a recess or opening 112 is formed in a silicon substrate 110. The opening 112 has exposed side surfaces 191 and a bottom surface 192. Next, at block 903 as illustrated by FIG. 6B, a process of HARP deposition is performed to deposit oxide 910 in the opening 112. The oxide 910 at least partially conforms to and contacts the surfaces 191, 192. The oxide 910 that was deposited using HARP is polished using chemical mechanical planarization (CMP) at block 905 as illustrated by FIG. 6C. The polishing aligns a top surface 995 of the oxide 910 with a top surface 996 of the substrate 110.

A recess 612 is formed in the substrate 110 and removes deposited oxide 910 at block 907 as indicated in FIG. 6D. The recess 612 exposes the surfaces 198 of the substrate and a top surface 199 of the oxide 610. Next, at block 909 as illustrated by FIG. 6E, a process of liner deposition is used to provide the liner 704 wherein the liner 704 at least partially conforms to and contacts the surfaces 198, 199 to provide a liner-encased recess 613. At block 911, illustrated by FIG. 6F, HDP deposition is used to fill the liner-encased recess 613 with oxide 920, and the oxide 920 that was deposited using HDP is polished using CMP. The oxide 920 at least partially conforms to and contacts the side surfaces 690 and bottom surface 691 of the liner 704. It can be seen that the oxide 920 and the liner 704 fill an upper portion 689 (e.g., relative to the surface 699 of the substrate 110) of the trench 687 and the oxide 910 fills a lower portion 688 (e.g., relative to the surface

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699 of the substrate 110) of the trench 687. At block 913, shown by FIG. 6G, a high-k metal gate 120 is formed above the liner 704 and the polished oxide 910 that was deposited using HDP. The gate 120 contacts the top surface 696 of the oxide 920 and the top surfaces 697 of the liner 704. It is noted the polishing in FIG. 6F, but illustrated in FIG. 6G, causes the top surface 696 of the oxide 920 and the top surfaces 697 of the liner 704 to align with a top surface 699 of the substrate 110. The resulting semiconductor device reduces or minimizes undesired oxygen diffusion and ingress from the deposited oxide into the gate 120 region.

FIG. 7 sets forth a first illustrative shallow trench isolation in a semiconductor device fabricated using the method of FIG. 5. A first layer of oxide 805 is provided using a HARP process. A liner 804 at least partially encases and contacts the first layer of oxide 805. The liner 804 may be fabricated using any insulator that is an oxygen sink or an oxygen barrier. Illustrative examples of oxygen sinks include, but are not limited to,  $\text{HfO}_2$  and/or  $\text{HfSiO}_4$ . An illustrative example of an oxygen barrier includes, but is not limited to, SiN. A second layer of oxide 803 is provided using, e.g., an HDP process. The liner 804 minimizes or reduces or prevents oxygen from diffusing into a gate region above the second layer of oxide 803. It can be seen that the oxide 803 fills an upper portion 989 (e.g., relative to the surface 990 of the substrate 110) of the trench 987 and the oxide 805 and liner 804 fill a lower portion 988 (e.g., relative to the surface 990 of the substrate 110) of the trench 987. Pursuant to various alternate embodiments, the second layer of oxide 803 may be provided using a HARP process in lieu of, or in addition to, an HDP process. It is assumed the oxygen concentration in an oxide formed by a HARP process is higher than the oxygen concentration in an oxide formed by an HDP process. It is also assumed that the oxygen concentration in oxide formed by one process will be approximately the same (e.g., within manufacturing variances) of an oxide concentration formed by the same process.

FIG. 8 sets forth a second illustrative shallow trench isolation in a semiconductor device fabricated using a modification to the method of FIG. 6. A first layer of oxide 705 is provided using a HARP process. A second layer of oxide 703 is provided using an HDP process. A liner 704 (FIGS. 6 and 8) at least partially encases and contacts sides of the second layer of oxide 703. The liner 704 may be fabricated using any insulator that is an oxygen sink or an oxygen barrier. Illustrative examples of oxygen sinks include, but are not limited to,  $\text{HfO}_2$  and/or  $\text{HfSiO}_4$ . An illustrative example of an oxygen barrier includes, but is not limited to, SiN. The liner 704 minimizes or reduces or prevents oxygen from diffusing into a gate region above the second layer of oxide 703. It can be seen that the oxide 703 and the liner 704 fill an upper portion 989 (e.g., relative to the surface 990 of the substrate 110) of the trench 987 and the oxide 705 fills a lower portion 988 (e.g., relative to the surface 990 of the substrate 110) of the trench 987. Pursuant to various alternate embodiments, the second layer of oxide 703 may be provided using a HARP process in lieu of, or in addition to, an HDP process.

Processing of semiconductors is largely or completely controlled by machines. Consequently, aspects of the present invention may take the form of a computer program product embodied in one or more computer readable medium(s) having computer readable program code embodied thereon. Any combination of one or more computer readable medium(s) may be utilized. The computer readable medium may be a computer readable signal medium or a computer readable storage medium. A computer readable storage medium does not include propagating signals and may be, for example, but not limited to, an electronic, magnetic, optical, electromag-

netic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. More specific examples (a non-exhaustive list) of the computer readable storage medium would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing. In the context of this document a computer readable storage medium may be any tangible, non-transitory medium that can contain, or store a program for use by or in connection with an instruction execution system, apparatus, or device.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

The corresponding structures, materials, acts, and equivalents of all means or step plus function elements in the claims below are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed. The description of the present invention has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the invention. The embodiments were chosen and described in order to best explain the principles of the invention and the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.

As such, various modifications and adaptations may become apparent to those skilled in the relevant arts in view of the foregoing description, when read in conjunction with the accompanying drawings and the appended claims. As but some examples, the use of other similar or equivalent mathematical expressions may be used by those skilled in the art. However, all such and similar modifications of the teachings of this invention will still fall within the scope of this invention.

What is claimed is:

1. A method for forming a semiconductor device comprising a shallow trench isolation, comprising:

forming a first opening for the shallow trench isolation on a semiconductor substrate;

performing a first process to deposit first oxide into the first opening;

forming a second opening to remove a portion of the first oxide from the first opening;

performing at least one second process to deposit second oxide into the second opening and over a remaining portion of the first oxide; and

forming at least a portion of the semiconductor device over and contacting at least a portion of a surface of the second oxide;

wherein the method further comprises, prior to performing the at least one second process, forming a liner at least partially conforming to interior surfaces of the second opening and a top surface of the remaining first oxide, wherein the liner at least partially encases sides of the second oxide after the second oxide is deposited by the high-density plasma chemical vapor deposition process.

2. The method of claim 1, wherein the first process is a high aspect-ratio process and the at least one second process is a high-density plasma chemical vapor deposition process.

3. The method of claim 1, wherein:

the method further comprises, prior to performing the first process, forming a liner at least partially conforming to interior surfaces of the first opening, wherein the liner at least partially encases sides of the deposited first oxide after the first process is performed to deposit the oxide into the first opening;

forming the second opening further comprises forming the second opening to remove, from the first opening, the portion of the first oxide and a corresponding portion of the liner that previously encased the sides of the portion of the first oxide; and

performing the at least one second process further comprises performing the at least one second process to deposit the second oxide over a remaining portion of the first oxide and a remaining portion of the liner.

4. The method of claim 3, wherein the first process is a high aspect-ratio process and the at least one second process is a high-density plasma chemical vapor deposition process and wherein the liner comprises a high-k material.

5. The method of claim 3, wherein the liner comprises at least one of an oxygen sink or an oxygen barrier.

6. The method of claim 5, wherein the first process is a high aspect-ratio process and the at least one second process is a high-density plasma chemical vapor deposition process.

7. The method of claim 5, wherein the first process is a high aspect-ratio process and the at least one second process is one or both of a high aspect-ratio process or a high-density plasma chemical vapor deposition process.

8. The method of claim 5, wherein the liner comprises at least one of  $\text{HfO}_2$ ,  $\text{HfSiO}_4$ , or  $\text{SiN}$ .

9. The method of claim 1, wherein the first process is a high aspect-ratio process and the at least one second process is a high-density plasma chemical vapor deposition process and wherein the liner comprises a high-k material.

10. The method of claim 1, wherein the liner comprises at least one of an oxygen sink or an oxygen barrier.

11. The method of claim 10, wherein the first process is a high aspect-ratio process and the at least one second process is a high-density plasma chemical vapor deposition process.

12. The method of claim 10, wherein the liner comprises at least one of  $\text{HfO}_2$ ,  $\text{HfSiO}_4$ , or  $\text{SiN}$ .

13. The method of claim 10, wherein the first process is a high aspect-ratio process and the at least one second process is one or both of a high aspect-ratio process or high-density plasma chemical vapor deposition process.

14. The method of claim 1, wherein the portion of the semiconductor device comprises a high dielectric constant metal gate.

15. The method of claim 1, wherein the semiconductor substrate comprises one of a silicon-on-insulator substrate or a bulk silicon substrate.